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EVALUATION OF STEEL ALLOYS SUBJECTED TO HIGH-FREQUENCY FLEXURAL--ETC(U)

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THE PROBLEM

Test types of high-strength steels and alloys for use in the diaphragms which operate as the sound source in long-range active sonar systems and are subjected to vibration at very high frequencies.

RESULTS

A 5 per cent chromium steel, Vasco-Jet, was found to perform adequately for the complete operational cycle of the vibrating diaphragms, without undue fatigue or early failure. This steel is far superior to No. 316 stainless, in the forged or centrifugally cast conditions, for this application.

RECOMMENDATIONS

1. Consider the 5 per cent chromium steel, Vasco-Jet, entirely satisfactory for the application for which it was tested.

2. Extend the use of 5 per cent chromium steel to other applications where flexing, good weldability, high temperature, and good fatigue resistance are necessary.

ADMINISTRATIVE INFORMATION

Work was performed by members of the Engineering Division under AS-02101-5, NE-051600-847.19 (NEL Problem E1-3). This report covers work from April 1958 to December 1959 and was approved for publication 17 December 1959.

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INTRODUCTION

The performance of the vibrating diaphragms which serve as the sound source in long-range active sonar systems and must be driven at large amplitudes is limited by the strength of the materials of which they are constructed. In an experimental sound source constructed for use at the Navy Electronics Laboratory the better known steels of the corrosion-resistant types proved disappointing, and considerable research and testing has been done to determine the best material for this application.

An alloy steel of extreme strength and unusual fatigue characteristics was needed to overcome the relatively short life expectancy of the original materials used in the diaphragms.

The alloy to be described here is available as 5 per cent chromium steel in the moderate price range, as compared with the super alloys normally suggested for applications of severe mechanical abuse.

MATERIALS AND DESIGNS TESTED

The first diaphragms tested were hot forged, in one stamping operation, of No. 316 corrosion-resistant steel (fig. 1).

Finish machining was done with all precautions taken to insure maintenance of optimum material characteristics. This diaphragm failed in the early stages of operation because of the poor fatigue strength of the material. In early operational runs, fatigue cracks appeared in some diaphragms and the number of such failures increased rapidly with continued use. This required considerable "down time" of the equipment to replace such inoperable pieces. It was decided that such conditions might be improved by redesigning and finding a material that had considerably greater fatigue resistance.

The new engineering concept involved a considerably smaller design set in a square rim as shown in figure 2.

New diaphragms were made using the same material but they were centrifugally cast instead of forged, to eliminate any forging stresses, voids, or other imperfections. A pilot run was made and tested. Results similar to those on the first design were noted. Fatigue cracking early in the testing indicated a need for a material that would be able to withstand the large number of reversals of stress involved in the operation.

A wide variety of alloys were considered and it was decided to investigate the use of a 5 per cent chromium low-alloy steel, Vasco-Jet 1000, for this application. This choice was made in consideration of the physical characteristics, machinability, and moderate price, even though corrosion resistance had to be sacrificed.

Description of Vasco-Jet

Vasco-Jet, manufactured by Vanadium Alloys Steel Company, Latrobe, Pennsylvania, is designed primarily for parts requiring high strength, fatigue resistance, toughness, ductility, and thermal stability.

The product has been found to be uniform in quality and condition, sound and free from foreign materials, and from internal and external defects detrimental to fabrication or to the performance of the part.

The following is a résumé of the information published by the manufacturer of this material: The 5 per cent chromium, air-hardening steel has superior properties for ultra-high-strength structural applications at both room and elevated temperatures. When heat-treated to 250,000 to 300,000 psi, it provides a combination of notch toughness,

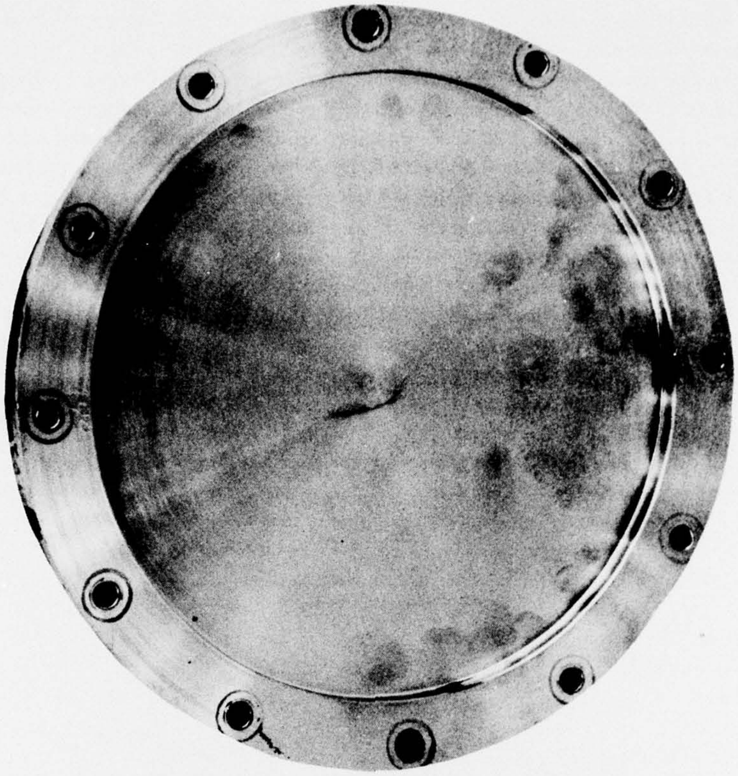
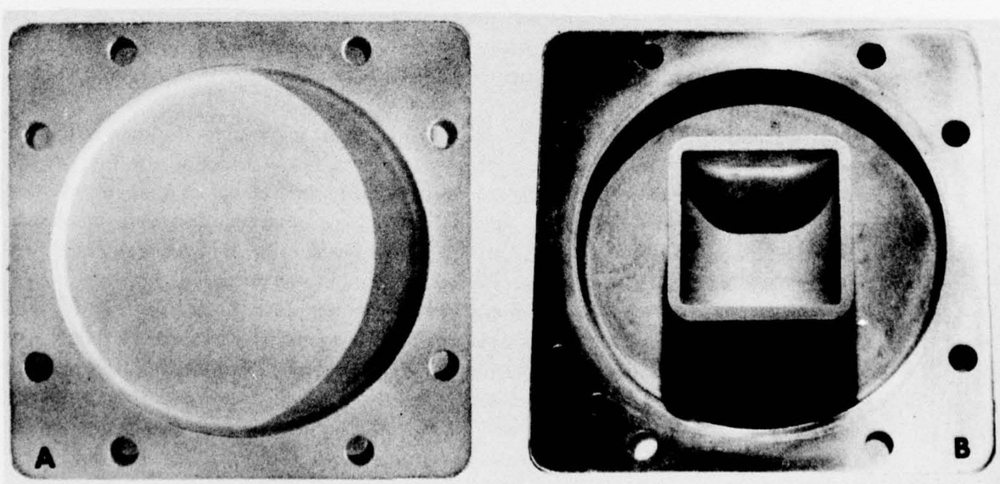


Figure 1. Hot forged No. 316 diaphragm constructed of No. 316 stainless steel.

Figure 2. Views of external and internal diaphragm faces (new design).



freedom from residual stress, and superior fatigue life as shown in the diaphragm application. This surpasses all other steel in strength-weight ratio, including the best titanium and precipitation hardening alloys as well as centrifugal-cast stainless. This steel alloy possesses a unique combination of maximum toughness at ultra-high-strength levels and an elevated temperature strength that is unsurpassed up to 1000°F. Its nominal composition of 0.40% C, 5.00% Cr, 1.30% Mo, and 0.50%V has proved, through extensive research, to be the lowest alloy analysis that will impart secondary hardening, a property that is essential to complete stress relief for maximum toughness and to strength retention at elevated temperatures.

The highly reproducible ultimate tensile strength, which is indicative of the cleanliness of the alloy, is achieved by tempering at 1000°F to 1050°F. This temper produced 265,000 to 290,000 psi tensile strength, 225,000 to 235,000 psi yield strength, 7.8 to 8.5% elongation and 15 to 20 foot-pounds Charpy V-notch impact strength. The impact value at —100°F is 15 foot-pounds and the fracture is completely tough and fibrous. During the notched bend test the material maintained full strength and good ductility with bottom radii as small as 0.009 inch, indicating minimum notch sensitivity.

The superior ductility and toughness of this relatively low alloy steel are associated with its unique heat treatment, which produces a stable, stress-free structure while avoiding most of the undesirable features that have beset other high-strength steels.

This material if tempered at 1000°F has the following properties:

Hardness (Rockwell)	C-54
Tensile strength	290,000 psi
Yield	235,000 psi
Elongation	7.8%
Reduction of area	28.1%
Modulus of elasticity	30.4×16^6 psi
Charpy V-notch impact	15.7 ft-lb

Vasco-Jet is readily machinable and weldable and can also be drawn with little difficulty. The NEL diaphragms were machined from annealed sheet stock. The machining can be accomplished with the normal high-speed steel tool bits with nominal feeds and speeds.

The core holders were cold-drawn from ⅛-inch stock to a depth of 9/16 inch. The remarkable ductility of the material is evidenced by the small radii required in the corners of the square (fig. 2). To state that this was accomplished simply and easily would be an exaggeration but the fact that it was done proves the unusual ability of the material in this type of fabrication.

The weldability of Vasco-Jet 1000 has been excellent. In welding the core holder to the diaphragm stub, only one pass of the heli-arc was required, while the face of the diaphragm was heated with another torch to provide uniformity of heat distribution (fig. 3). Penetration was good and very little clean-up was necessary. No weakness, cracking or breakdown has shown up in the cup or weld area of the diaphragms. The usual precautions for hardenable steels should be observed including annealing, preheating, slow cooling, and re-annealing before heat-treating.

After welding, the parts were annealed and then magnafluxed in order to detect any surface imperfections that would cause stress concentrations. They were given the full heat treatment in an endothermic atmosphere with controlled dewpoint, followed by four tempering cycles. The extreme care in the welding cycle was made necessary by the critical need for flatness and parallelism of the diaphragm faces. The foregoing

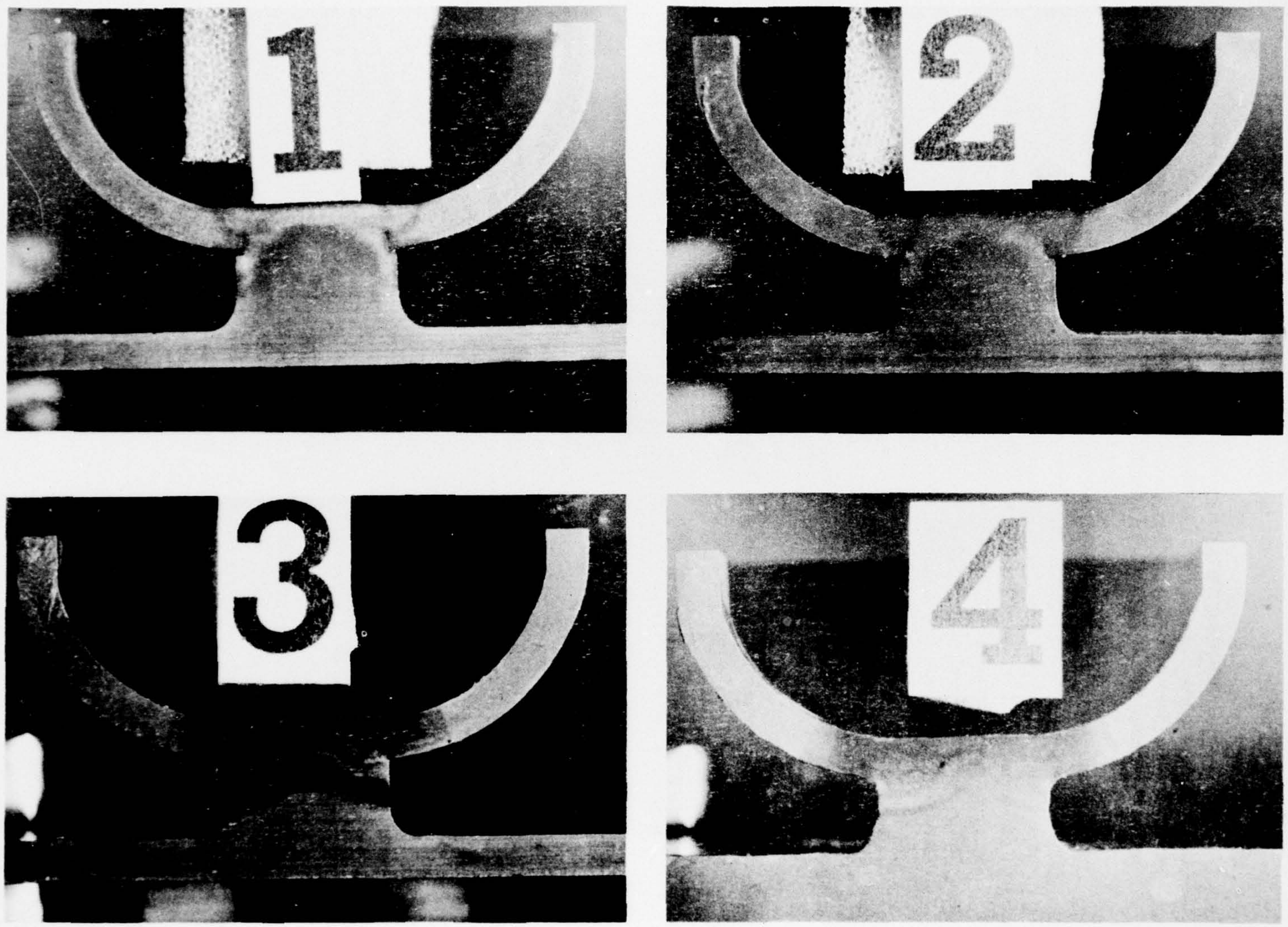


Figure 3. Four views of the steps in research for welding the cup to the plate of the diaphragm.

process should be followed carefully for close tolerance work but when extreme dimensional accuracy is not required, the second annealing may be omitted if the material is to be heat treated. In the welding of tensile specimens for test purposes, the weld bead may be ground off or left on. Fractures on these tests occurred only outside the weld or heat-affected zone.

Metals of this type, deriving their strength from the tempering and secondary hardening of martinsite, tend to be structurally stable and predictable. Parts can be designed with extremely deep hardenability, for this material can be fully hardened in heavy sections by simply air cooling from between 1800°F to 1900°F.

Because it is cooled slowly and uniformly, a structural part arrives at room temperature with much less residual stress than would be obtained from more drastic oil quenching. The very high hardenability also provides assurance against another problem of low-alloy steels, which, when heat treated at unspecified temperatures, behave erratically.

The tempering characteristics of Vasco-Jet are particularly outstanding. A secondary hardness peak (similar to that found with high-speed steel) appears in the vicinity of 950°F, and all tempering is conducted at still higher temperatures to obtain the best combination of strength and toughness. Thus, residual stresses that may have been set up in quenching are essentially all removed by the very high temperature stress relief.

Metallurgical examinations were made in the weld, heat-affected, and parent material zonal areas. The photomacrographs (fig. 3) show the regularity of structures and the homogeneity of the material in all three zones. At 500X magnification, the weld and heat-affected zones are practically indistinguishable.

The one weak feature of this material is its lack of corrosion resistance, which requires that it be coated before using. A report on this aspect of the problem is being prepared.

TEST PROCEDURES

Actual operating conditions were used to make tests on the specimen diaphragms shipped by the manufacturer.

A diaphragm was mounted on a vibrating head and driven at standard amplitudes for five days without indication of breakdown. This proved Vasco-Jet to be superior to No. 316 stainless which fatigued and cracked in less than 100 hours. Subsequently the Vasco-Jet diaphragm was subjected to more power than normal and, after several hours, breakdown occurred in its center. This apparently resulted from cavitation, which occurs when the driving amplitude is greater than normal, rather than from fatigue (fig. 4).

An experimental test run was then made using seven diaphragms in continuous operation at a depth of 70 feet in the San Diego Bay. This test was continued for over 800 hours (fig. 5).

The diaphragms were first examined carefully for any flaw or defect that might be deleterious to the tests. Several different types of coatings were applied to protect against corrosion. After the tests the coatings were examined for any flaws or pinholes that might have negated the tests.

After the tests the frames were removed from the water and examinations revealed very litle damage to the protective coatings. The coatings were stripped from the diaphragms with suitable solvents, and the surfaces subjected to a very careful examination and inspection. The diaphragms were found to be in very good condition, showing no buckling, cracking, movement of metal, or other ill effects from the testing. Figure 6 shows enlarged views of the central areas of the external face of the diaphragms after the 800-hour operational test run.

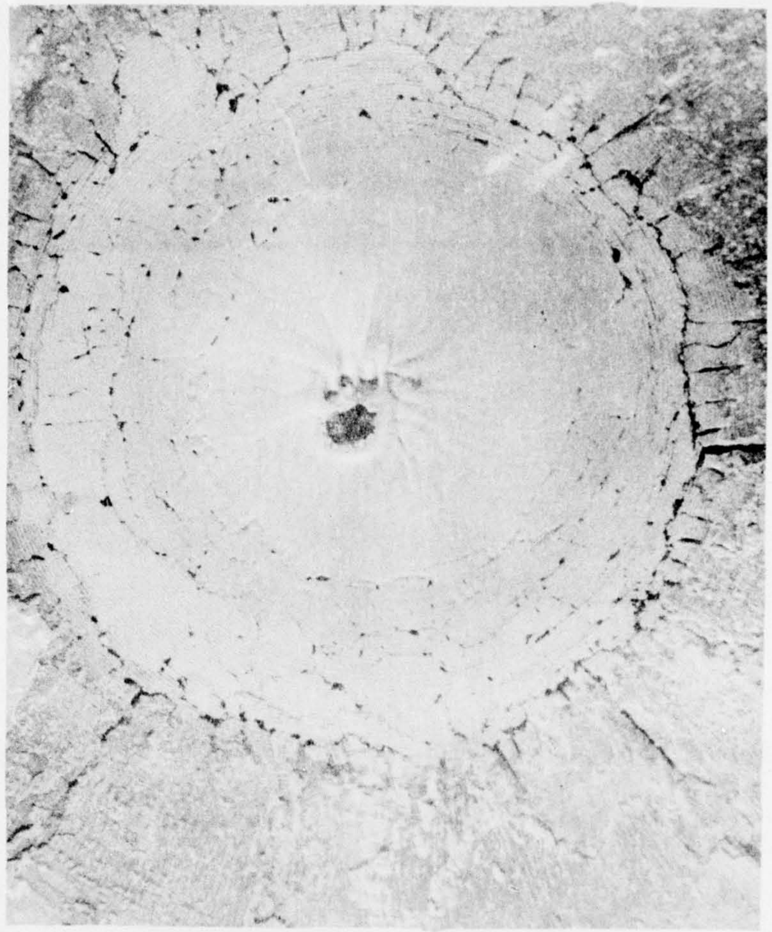


Figure 4. Fatigued diaphragm face.

CONCLUSIONS

1. The 5 per cent chromium alloy, Vasco-Jet, is an exceptional material and entirely suited to the application for which it was tested.

2. Major importance is also attached to the ease of fabrication. The material machines very well, is capable of being drawn with relative ease and welds readily when proper welding procedures are used. By proper welding techniques, the weld areas become an integral part of the metal and appear to be stronger than the parent material.

RECOMMENDATIONS

The characteristics of this material are such that it should be given consideration in other projects that require high strength and high shock and fatigue strengths at ambient and elevated temperatures (to 1000°F).

Figure 5. Test rack after 800-hour underwater test in San Diego Bay.

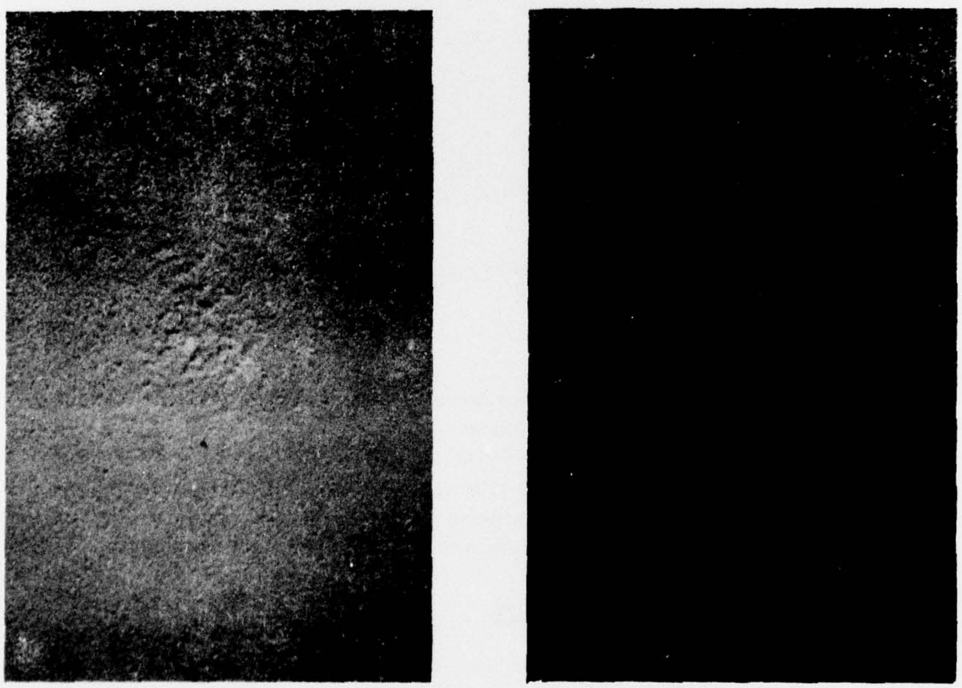


Figure 6. Two diaphragms after completion of the 800-hour test and after stripping the coating.

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2. Steel — Test results

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